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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04L 9/08	A1	(11) International Publication Number: WO 97/31450
		(43) International Publication Date: 28 August 1997 (28.08.97)

(21) International Application Number: PCT/US97/02984

(22) International Filing Date: 21 February 1997 (21.02.97)

(30) Priority Data:
08/605,427 22 February 1996 (22.02.96) US

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(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: KEY REPLACEMENT IN A PUBLIC KEY CRYPTOSYSTEM

(57) Abstract

Improved key management is provided by a public key replacement apparatus and method for operating over insecure networks. An active public key and an encrypted replacement public key are provided by a key server to nodes where the active key is used to encrypt and verify messages. To replace the active public key with the replacement public key, a key replacement message is sent to the node. The key replacement message contains the key for decrypting the replacement public key and contains an encrypted next replacement key. The key replacement message is signed by the active public key and the replacement public key. Nodes are implemented by a computer, a smart card, a stored data card in combination with a publicly accessible node machine, or other apparatus for sending and/or receiving messages. In a particular application, a financial transaction network, nodes are consumer nodes, merchant nodes, or both, and transactions are securely sent over a possible insecure network.

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KEY REPLACEMENT IN A PUBLIC KEY CRYPTOSYSTEM

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FIELD OF THE INVENTION

The present invention relates to the field of secure transaction processing, more specifically to the field of public key encryption of transaction data.

BACKGROUND ART

A cryptographic system is a system for sending a message from a sender to a receiver over a medium so that the message is "secure", that is, so that only the intended receiver can recover the message. A cryptographic system converts a message, referred to as "plaintext" into an encrypted format, known as "ciphertext." The encryption is accomplished by manipulating or transforming the message using a "cipher key" or keys. The receiver "decrypts" the message, that is, converts it from ciphertext to plaintext, by reversing the manipulation or transformation process using the cipher key or keys. So long as only the sender and receiver have knowledge of the cipher key, such an encrypted transmission is secure.

A "classical" cryptosystem is a cryptosystem in which the enciphering information can be used to determine the deciphering information. To provide security, a classical cryptosystem requires that

the enciphering key be kept secret and provided to users of the system over secure channels. Secure channels, such as secret couriers, secure telephone transmission lines, or the like, are often impractical and expensive.

A system that eliminates the difficulties of exchanging a secure enciphering key is known as "public key encryption." U.S. Patent no. 4,405,829 and Diffie and Hellman, "New Directions in Cryptography," IEEE Trans. Inform. Theory, vol. IT-22, pp. 644-654, Nov. 1976, teach public key encryption. With public key encryption, two keys are used, a private key and a public key. The keys are symmetrical, i.e., either key can be the public key or the private key -- the labels "public" and "private" simply identify which key is made available to the public, and which key is kept private by the "owner" of the key pair. Public key encryption is applied to a "message". A message is text, graphics, data, or other digitized information, and public key encryption is used to either encrypt the message making it unreadable by anyone unless they have the private key or to create a readable message with a digital signature. A digital signature is created for a specific message using the private key. Only a person with knowledge of the private key is able to create a valid digital signature for a given message, so this prevents others from generating or altering messages and creating forged signatures.

To keep a message to the key owner private, the sender of the message will obtain the recipient's public key and use that key to encrypt the message. Before encryption, the message is said to be a "plain text" message (although the message might not be text at all) and following encryption, the message is said to be a "cipher text" message. The cipher text message can only be converted back to the

original plain text message by a decryptor knowing the recipient's private key (the other key in the recipient's key pair). Of course, with enough computing power and a poorly chosen encryption scheme or key pair, a decryptor might be able to extract the plain text message without knowing the key. It is assumed here that a robust encryption scheme is selected such that the private key is indeed required.

A message is digitally "signed" by the key owner by applying a key and the message to a digital authenticator, which outputs a digital signature to be attached to the message.xxThe recipient of the message can then apply the message, the digital signature and the key used to generate the signature to an authenticator which will indicate whether or not the digital signature was generated from that exact message and the key. With public key signatures, the private key is used to generate the digital signature and the public key is used to verify the signature.

In a transaction processing system, such as with the use of smart cards or terminals, a transaction is formed into a message and encrypted using the secret key of the operator of the transaction processing system. The term "smart card" refers to a card such as a bankcard which contains data storage and computing ability, as opposed to a more conventional card, which contains only data storage, typically in the form of data stored on a magnetic stripe. A terminal might be an automatic teller machine (ATM), a terminal in a bank, a home personal computer, or other means for a user to send and receive data.

U.S. Patent no. 4,972,472 issued to Brown et al. shows a method and apparatus for changing a master key in a cryptographic system. That system provides storage locations for three keys: a pending key,

an active key and a retired key, When a key is to be replaced, the new key is stored in pending key location. When a key update command is given, the existing active key is shifted to the retired key location and the pending key is shifted into the active key location. The retired key is used for applications which have not yet been made aware of the key change. Over time, applications are made aware of the change and shift over from using the retired key to using the active key.

One disadvantage of the Brown et al. system is that a replacement key could be sent by someone with unauthorized access to the channel used to transmit the keys. Thus, the key replacement apparatus is only useful where the channel in which the replacement keys are sent out is secure.

As should be apparent, anyone knowing the key owner's secret key can pose as the key owner, read the key owner's messages and create or alter messages sent in the name of the key owner. In an insecure system, unauthorized persons have the ability to view the traffic between the key server and the key users, whether or not such eavesdroppers know the secret keys being used. Once a secret key is compromised, it can no longer serve its purposes of making messages private.

One problem with a distributed system of smart cards or terminals is that they are widely distributed and when a secret key is compromised, it is impractical for all the holders of the smart cards or users of terminals to return to the central key authority to exchange keys or otherwise establish a clear channel to transmit the replacement key.

Another problem is the rapid and continual increase in computing power available. The impending obsolescence of DES (Data Encryption Standard -- a secret key algorithm) is in part due to the subsequent developments in computing. At one time, a noted cryptologist calculated that a message encoded with DES could be decrypted without knowing the secret key in a month using $20 million in computer hardware. Recently, a group of noted cryptographers estimated that a $10 million investment in hardware would recover a DES key in 6 minutes (see "Minimal Key Lengths for Symmetric Ciphers to Provide Adequate Commercial Security" Blaze et al., A Report by an Ad Hoc Group of Cryptographers and Computer Scientists, January 1996). Thus, what is needed is a capability to increase security of keys as large amounts of raw computing power becomes more accessible to potential attackers.

SUMMARY OF THE INVENTION

Improved key management is provided by virtue of the present invention. In one embodiment, an active public key and an encrypted replacement public key are provided by a key server to nodes of the network. Each time a key replacement is performed, the active public key is discarded, the replacement public key replaces the active public key, and the next replacement public key replaces the replacement public key. Thus, two public keys are recognizable at a node at any one time. These keys are network-wide keys and are used in addition to any node-specific key pairs.

Each node includes a system for sending and receiving messages to and from the network, such as a networked personal computer, a smart card, or a data card combined with a public terminal. Initially, each node is provided with the active public key and the replacement

public key, along with any default node "owned" key pairs. The network-wide public keys have corresponding private keys which are owned by the operator of the network. The initial keying of the node is done over a secure channel between the node and the network operator. While other secure channels are possible, the simplest method is for the network operator to maintain control over some element of the node during the process of installing the initial public key information.

A node uses the active public key (the network active public key) to encrypt or sign messages destined for the key server or a third party. When the active private key has been compromised or is at risk of calculation, the key server sends out a key replacement message containing the replacement key and the encrypted next replacement key, replaces the active private key from the replacement private key storage and places the encrypted next replacement private key into the replacement private key storage. As should be apparent, according to this chain of succession, each new key (public or private) is first a next replacement key, then a replacement key, then an active key, then finally it is discarded. At the node, the active public key is replaced with the replacement public key and the replacement public key is replaced with the the next replacement public key.

The key replacement message also contains the key for decrypting the replacement public key and the message is signed by the active private key and the replacement private key. Because the message is signed by the replacement private key, it could only come from an entity with knowledge of the replacement private key before the message was sent. The decryption used on the encrypted next

replacement key need not be the same as that used on the encrypted replacement key.

If brute force computation of the active public/private key pair becomes feasible, that pair is deemed compromised, and the key replacement process is performed. Because the replacement public key is only available to an attacker in encrypted form, increasing computing power does not weaken the encrypted replacement public key as fast as the active public key, since many more operations are needed to decrypt the replacement public key and to then reverse engineer the replacement public key, compared to just reverse engineering the active public key. Thus, encryption of the replacement public key until it is needed at the active public key helps ensure that the replacement key cannot be computationally determined with the same order of magnitude of computing power required to computationally determine the active public key.

In a specific embodiment, multiple nodes of an insecure network are defined by the interconnected computers (personal computers, workstations, etc.) configured with the ability to send messages from one node to another or from one node to many nodes. At each node, memory is maintained with the active public key, the encrypted replacement public key, and the node's specific private/public key pair. Typically, a node is associated with one user, such as an individual using the node to send messages to other users at other nodes. For example, a node could be a personal computer connected to the Internet and the messages could be financial transactions transmitted by the user to banks and/or merchants.

In an alternate specific embodiment, the key user uses a smart card to store the active public key and the encrypted replacement

public key, the key server is a financial institution and the message sent between the key user and the key server are financial transactions. In yet another embodiment, user specific data is stored on a card held by the user and the card is inserted or read by a publicly available terminal to form the node system.

In other embodiments, a node maintains multiple sets of active and replacement public keys, one from each of a plurality of master nodes. This allows for independent secure communications with different master nodes.

A further understanding of the nature and advantages of the inventions herein may be realized by reference to the remaining portions of the specifications and the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of a network in which the present invention is used;

Figure 2 is a flow chart of a process of replacing a key in a secure manner;

Figure 3 is a block diagram of a specific application wherein the network is used to carry secure traffic between consumers and merchants; and

Figure 4 is a schematic diagram of a portion of a key replacement message.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A system for key replacement in a public key cryptography system using encryption is described. In the following description numerous specific details, such as key length, encryption algorithm, etc., are set forth in detail in order to provide a more thorough description of the present invention. It will be apparent, however, to one skilled in the art, that the present invention may be practiced without these specific details. In other instances, well known features have not been described in detail so as not to unnecessarily obscure the present invention.

Figure 1 is a block diagram of a network 10 which connects two nodes 12 (user node 1 and user node 2) to each other and to a key server 16. Although only two nodes are shown for clarity, it should be apparent that many more nodes are possible. As should also be apparent, network 10 need not be actually insecure, but is assumed to be so. An insecure network is a network where the possibility exists that an eavesdropper 18 is listening to network traffic.

Each node 12 is shown coupled to its own data key storage 20. User node 1 is shown with a message block 22 containing a message intended for delivery over network 10 to user node 2. Data key storage 20 contains storage for the active public key, the encrypted replacement public key and the user node's private/public key pair. Typically, the nodes are associated with individuals and organizations who are network users and operate and control their respective nodes, to send messages as desired, read received messages, change the user node key pair and publish the user node public key.

The following notation is used herein: "A" refers to the active key pair, with "Apu" being the active public key and "Apr" being the active private key. Likewise, the replacement key pair is "R", with "Rpu" being the replacement public key and "Rpr" being the replacement private key. Encryption of a message M using a key K is written as E_K(M), while decryption of the encrypted message E_K(M) using key K is written as D_K(E_K(M)). This notation refers to both secret key encryption and public key encryption, although when referring only to public key encryption, the more specific notation E_Kpu(M) and D_Kpr (M) is used to clearly indicate the different components of the key or key pairs are used for encryption and decryption. The functions E_K() and D_K() need not be distinct. For example, where encryption is the exclusive OR'ing of the message and the key, E_K() and D_K() are the same functions.

The user key pair is denoted by "U", with the public and private keys being "Upu" and "Upr" respectively. A user key pair is distinguished from the active key pair and the replacement key pair in that the latter two pairs are used system wide, while a user key pair is generated and maintained by the user of a specific node.

Often, to ensure that the contents of a message have not been altered and to verify the node from which a message was sent, the message is "digitally signed". To digitally sign a message, a node generates a digital signature block from the message contents and the node's private key as is known in the art. The digital signature block is then attached to the message. Because of the way the digital signature block is generated, it would be extremely difficult to determine a digital signature block for a message without knowing the private key used, and the digital signature blocks for the original message and an

altered version of that message are unlikely to be the same. In a digital signature system, the recipient can apply the message, the digital signature block and the sender's public key to a signature verifier. The signature verifier reports whether or not that message was the exact message used to generate the digital signature. Herein, a message with a digital signature is denoted as (M) [K], where M is the message and [K] is the digital signature generated for message M using key K.

In the example described below, only one master node is used and the operator of that node controls key server 16 and thus controls, or "owns", the active public/private key pair and the replacement public/private key pair. Thus, the operator of key server 16 knows, and keeps secret, the active private key and the replacement private key. In some systems, the active and replacement key pairs are referred to as "system key pairs" to distinguish them from user key pairs.

In Figure 1, key server 16 is shown coupled to a key server public key database 24 for holding the public keys of each participating node. Key server 16 is also shown coupled to receive "replace key" commands from a central public key controller 26, which is in turn coupled to storage 28 for the active private key (Apr) and storage 30 for the replacement private key (Rpr). Key server 16 sends messages, such as message 40 and key replacement message 42 to nodes 12 over network 10. In a preferred embodiment, storage 28 and storage 30 are not located in the same physical location or secured by a common security method, so that a single breach of security which allows access to one key will not allow access to the other key.

It is assumed that eavesdropper 18 has the capability to send messages which appear to be sent by a node other than itself, such as node 12 or key server 16. With this capability, eavesdropper 18 might

send a key replacement message to user node 1 falsely indicating that the message was sent by key server 16. This forged message would instruct user node 1 to update Apu to a value provided (apparently) by key server 16. If eavesdropper 18 sends a false Apu value which is paired with a private key known to eavesdropper 18, and if user node 1 accepts the message as authentic and changes Apu, eavesdropper 18 will be able to decrypt all subsequent messages encrypted with the false Apu. Eavesdropper 18 could also send key server 16 a message apparently from user node 1 where the message indicates that user node 1 has changed its user public key, U1pu, to a public key which is paired with a private key known by eavesdropper 18. If accepted by key server 16, eavesdropper 18 would then be able to decrypt any messages from key server 16 which are encrypted with U1pu.

In operation, of course, user nodes 12 and key server 16 are more cautious. To securely send a message from one node to another, the sender must obtain the recipient's real public key and use that key to encrypt the message. To know the real key for the recipient, the sender must have some way of assuring that the public key for the recipient is correct. The public keys for specific nodes are obtained by querying key server 16, which supplies the public keys from node key database 24. These public keys are the keys published by the user nodes.

Since network 10 is deemed insecure, it is assumed that if user node 1 requests a public key from user node 2, eavesdropper 18 could stand in place of user node 2, intercept the request, reply with a key known to eavesdropper 18, intercept the message and decrypt the message. To prevent this scenario, the user nodes supply their public keys to key server 16 using a message which could not have been sent

from eavesdropper 18 and which is not readable by eavesdropper 18. To do this, key server 16 needs to engage in one initial secure interaction with each node, to get the node's public key and be assured that it was sent from that node. Fortunately, this is easily done during the set-up of a node. For example, if the node is a personal computer, a distribution diskette could contain an initial user key pair or the key pair could be distributed over the telephone. If each message from a node to key server 16 is digitally signed with the node's private key, key server 16 is assured that it was not sent by eavesdropper 18. If the message is also encrypted with the active public key, eavesdropper 18 cannot read the message. If one user compromises the private key of its node, the security breach is confined to that user's node and is easily remedied by sending a new key over a secure channel to that node (e.g., sending a new smart card to the user of the node). However, if the active public key is compromised, without more, each node in the entire system would have to be reinitialized with the replacement public key over secure channels. The secure channel is not needed with the present invention where only the active key is compromised, whether it be by authorized access to storage 28 or by computational brute force.

Key server 16 accepts key replacement commands from central public key controller 26, which decides when to replace the active public key, Apu. Central public key controller 26 generates a new replacement key pair each time the active key is to be replaced with the existing replacement key, and updates storage 28 and 30 accordingly. Herein the new key pair is referred to as (R1pu, R1pr), and subsequently generated new pairs are (R2pu, R2pr), (R3pu, R3pr), etc. The process of secure replacement of the public key over an insecure network is shown in Figure 2.

Figure 2 is a flow chart of a process for publishing a public key and for replacing a public key when its paired private key is compromised or insufficiently secure. In the example shown, the public key being replaced is Apu, the active public key of key server 16. The active public key might not be actually compromised, as key replacement might be called for as technology advances to the point where it is conceivable that Apu could be calculated by brute force, in which case the replacement key would be a longer or more complex key. Alternatively, key replacement could occur on a regular, periodic basis, since a secure channel is not needed. The process of key replacement must occur both at key server 16 and at nodes 12, since keys are paired. Thus, when the private key is replaced in storage 28, that replaced key cannot be used unless the public key stored in data storage 20 is also replaced.

Referring again to Figure 2, the steps of the process shown there are labeled S1, S2, S3, etc., for ease of reference. In step S1, Apu and E_X(Rpu) are supplied initially to each node over a secure channel. As explained above, this step need only be done once. The key replacement process begins with step S2, where a new key pair (R1pu, R1pr) is generated). This is done by either key server 16 or central public key controller 26. In step S3, key server 16 sends a key replacement message (such as key replacement message 42 shown in Figure 1 and in detail in Figure 4) to each node 12, or broadcasts a single key replacement message. A number of fields of key replacement message 42 are shown in Figure 4. These fields include the next replacement public key, data necessary to decode the replacem t public key, and digital signatures for the message.

The entire key replacement message is digitally signed by both the active private key, Apr, and the private replacement key, Rpr. Additionally, the message might be encrypted using the active public key, Apu. However, given that Apu might have been compromised, a more secure method is to send separate messages to each node, each encrypted with the node's public key. If the key replacement message is encrypted , it is decrypted by the node.

Figure 4 shows key replacement message 42 in greater detail. This message 42 is sent from key server 16 to node 12 as part of the key replacement process. The fields shown are X, D_X(), E_X1(R1pu), SIG (Apr) and SIG(Rpr).

The key replacement process has the following steps: 1) a new key pair is generated by central public key controller 26, 2) central public key controller 26 moves the existing replacement private key from storage 30 to storage 28, making it the new active private key, 3) central public key controller 26 moves the next replacement private key to storage 30, making it the new replacement private key, 4) central public key controller 26 sends a key replacement command to key server 16, where the key replacement command includes the new public key from the next replacement key pair, and 5) the next replacement public key is inserted into message 42 as field E_X1(R1pu). This example is for the first generation of key replacement. In the second generation, the field is designated E_X2(R2pu), to be consistent with the conventions used here. Because the keys are paired, these steps must be done together, otherwise messages might be encrypted with one generation of keys and decryption would be attempted with a different generation of keys.

The field X contains the decryption key for E_X(Rpu), the encrypted replacement key which resides at the node to which message 42 is sent. The field D_X() contains the decryption method for E_X(Rpu). In some embodiments, D_X() is known ahead of time as the user node, so this field is not needed. This field contains, depending on implementation, parameters and/or program instructions for the decoding process. With the X and D_X() fields, the node can decrypt the replacement public key.

The field E_X1(R1pu) is generated by encrypting the next replacement public key, now designated R1pu, according to the encryption function E_X1(). The encryption of R1pu can be performed either by central public key controller 26 of key server 16.

The fields SIG(Apr) and SIG(Rpr) are digital signatures, also sometimes referred to as [Apr] and [Rpr], respectively. The digital signature SIG(Apr) is a signature of message 42 using the currently active private key, i.e., the contents of storage 28 before the replacement is done. This digital signature is verified by applying message 42 and the other key which is paired with the signing key Apr, namely active public key Apu, to a verifier. Similarly, the digital signature SIG(Rpr) is verified by applying message 42 and the replacement public key, Rpu, to the verifier. Of course, the replacement public key, Rpu, must be decrypted before it can be applied to the verifier.

If both digital signatures verify message 42, the node replaces E_X(Rpu) with E_X1(R1pu) and replaces Apu with Rpu. In this way, the active public key stored in storage 20 is replaced with the replacement public key, which was also stored in storage 20, and the replacement replacement public key extracted from message 42 is

stored in storage 20 as the replacement public key. Of course the next replacement public key is encrypted and stored in its encrypted form, until the next generation when it is needed as the active public key.

Referring again to Figure 2, in step S4, the digital signature [Apr] is verified using Apu. If the digital signature does not match the message and the active public key (Apu), then the key replacement message is ignored (S5). In some embodiments, the node will send a message to key server 16 to the effect that an unauthorized key replacement message has apparently been sent.

If the digital signature [Apr] is verified, the replacement public key, Rpu, is extracted from the key replacement message (S6), using the key and decryption method provided by the key replacement message.

Once the replacement public key, Rpu, is decrypted, it can be used to verify the digital signature [Rpr] of the key replacement message (S7). If the digital signature [Rpr] does not verify, the process flows to step S5, otherwise it continues to step S8. In step S8, the node replaces Apu in storage 20 with the replacement public key, Rpu and replaces E_X(Rpu) in storage 20 with the encrypted next replacement public key, E_X1(R1pu) (S9).

At this point, key replacement is complete. If desired, the process can be repeated (S10) so that yet another new key pair (R2pu, R2pr) is generated, where R2pu becomes the replacement key with R1pu being the active key. Performing the process twice is useful where both the active key and the replacement key are nearing obsolescence. If the replacement key is only ever generally available in encrypted form, any computation to break the keys will take longer to

break the replacement key than the active key, since the encryption on the replacement public key must first be broken before the replacement private key can be attacked.

If the replacement private key is physically compromised, but the active private key is not, this method will still securely transmit the key replacement message over the insecure network, since it is signed by the active private key. Of course, in this situation, the key replacement would be done twice in quick succession, in order to retire the compromised replacement key.

Figure 3 shows a specific application of the key replacement system, a financial transaction system 100. Several elements of Figure 1 are shown again in Figure 3: network 10, eavesdropper 18, node public key database 24, central public key controller 26, and storage 28 and 30. System 100 is used to facilitate a secure transaction, such as a credit or debit card transaction between a consumer at a consumer node 102 and a merchant at a merchant node 104 via network 10. Consumer node 102 is implemented as a personal computer, a smart card, or a publicly accessible terminal. If consumer node 102 is a publicly accessible terminal, such as an ATM, kiosk or point-of-sale (POS) terminal, data personal to the consumer would be stored separately (labeled "personal storage 110" in the figure), and would include key storage 106 similar to key storage 20 shown in Figure 1 and a financial database 108, each coupled to consumer node 102. Key storage 106 coupled to the consumer node 102 stores the central public keys and the consumer's keys, public and private, as well as other consumer specific data. Merchant node 104 also is coupled to its own key storage 106, which stores the central public keys and merchant

keys. If a node 12 is both a consumer and a merchant node, it might use the same keys for both buying and selling transactions.

A key server 112 is coupled to network 10 and central public controller 26. Key server 112 serves the same purpose as key server 16 of Figure 1, as well as an additional purpose of being an authorization server which uses secure links to a financial network to secure authorization and/or funds for transactions entered into by a consumer at consumer node 102.

A transaction is shown in Figure 3 by paths numbered 1 through 5. A consumer initiates the transaction. For example, a consumer might browse publicly available files of offerings of a merchant, such as World Wide Web pages on the Internet and decide to order a product. To pay for the product, the consumer sends a secure message to the merchant. To do this, consumer node 102 sends a public key request message to key server 112 (path 1). Key server then responds with a public key value message back to consumer node 102 indicating the public key for merchant node 104 (path 2). These two messages are sent secured by the methods described above. The message to key server 112 and its response are encrypted and/or signed using the public and private keys of key server 112, so those keys must be kept especially secure.

The consumer node 102 then sends the transaction data to merchant node 104 in a message encrypted with the public key for merchant nod 104 and signed by the private key for consumer node 102. For example, the message might say "charge item #123, quantity 1, to card number 47##-####-####-####, expiration date mm/yy". This message is decryptable only by the merchant node, since the merchant node private key is required for decryption. Merchant node 104 uses

this information to process the payment over the secure financial network.xxThe merchant can verify the signature on the transaction using the consumer's public key, which can be obtained from key server 112.

Before submitting the payment over the financial network, merchant node 104 can check card authorization either through the financial network or through key server 112 (via path 4), which would then check for authorization and secure funds. Key server 112 then (path 5) securely reports the results of the authorization to consumer node 102 as well as merchant node 104.

As should be apparent, the above-described method and apparatus might also be used to perform bill payment or the secure network might be entirely replaced by network 10, in which case issuer banks (who issue credit, debit or bank cards to consumers), acquirer banks (who acquire transactions from merchants), and settlement systems could be nodes on network 10. Bill payment might be performed as taught by U. S. Patent No. 5,465,206 (Appl. Serial No.: 08/146, 515), issued to Hilt, et al. on November 7, 1995 and commonly owned with the present application. That patent is incorporated by reference herein.

In summary, the above detailed description has described a method and apparatus for securely distributing keys over an insecure network from a central source, to allow secure communications between nodes and a key server and from nodes to nodes, even where each node has no means to verify the identity of any other node except the key server. The keys that are distributed are the network public keys.

The above description is illustrative and not restrictive. Many variations of the invention will become apparent to those of skill in the art upon review of this disclosure. Merely by way of example, the apparatus might be implemented wholly in general purpose computers suitably programmed or could be implemented by special purpose hardware or integrated circuitry. Also, the above description shows the application of key replacement to the public key of a network, i.e., the master node's public key. However, the same key replacement methods and apparatus could also be used for more secure replacement of user node keys. In such a system, the key server would maintain user public keys and replacement user public keys.

The scope of the invention should, therefore, be determined not with reference to the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents.

WHAT IS CLAIMED IS:

1. A method of secure key replacement in a public key cryptography system, wherein secure messages are transmitted from a first node to a second node over a network presumed to be insecure, the method comprising the steps of:

generating , at the first node, an active key pair comprising an active private key and an active public key, wherein the active key pair is used to secure messages between the first and second nodes according to a public key scheme;

generating, at the first node, a replacement key pair comprising a replacement private key and a replacement public key;

encrypting , at the first node, the replacement public key to form a encrypted replacement public key;

sending the active public key and the encrypted replacement public key from the first node to the second node over a secure channel;

when the active key pair is to be retired, performing the steps of:

generating, at the first node, the next replacement key pair comprising the next replacement private key and the next replacement public key;

encrypting , at the first node, the next replacement public key to form an encrypted next replacement public key;

sending the encrypted next replacement public key from the first node to the second node over the network; and

decrypting , at the second node, the encrypted replacement public key; and

thereafter using the replacement key pair as the active key pair, for use in securing messages between the first and second nodes, and thereafter using the next replacement key pair in place of the replacement key pair, which is stored for use in a subsequent key pair retiring step.

2. The method of claim 1, wherein the process of retiring the active key pair further comprises the steps of:

sending, from the first node to the second node, a decryption key for decrypting the encrypted replacement public key; and

sending, from the first node to the second node, digital signatures for providing to the second node that the active private key and the replacement private key were known to the initiator of the process for retiring the active key pair.

3. The method of claim 1, further comprising the step of sending a message from the first node to the second node, wherein the message is digitally signed using either the active private key or the replacement private key or both.

4. The method of claim 1, further comprising the step of sending a message from the second node to the first node, wherein the message is encrypted using either the active public key or the replacement public key or both.

5. The method of claim 1, wherein replacement of the encrypted replacement public key with the encrypted next replacement

public key is performed at the second node and is performed synchronously with the replacement of the active private key with the replacement private key and the replacement of the replacement private key with the next replacement private key at the first node.

6. The method of claim 1, wherein the first node is a key server node and the second node is one of a plurality of user nodes.

7. The method of claim 1, wherein the first node is one of a plurality of user nodes and the second node is a key server node.

8. The method of claim 1, wherein the network connects a plurality of nodes to each other, the plurality of nodes comprising a plurality of key server nodes and a plurality of user nodes.

9. The method of claim 1, further comprising the step of repeating the step of retiring a key pair.

10. A method of secure key replacement in a public key cryptography system, wherein a first node stores an active private key and a second node stores an active public key and a replacement public key, the active public key and the active private key being an active key pair used for public key cryptography and the replacement public key and the replacement private key being a replacement key pair, and wherein the replacement public key is stored as an encrypted replacement public key at the second node, the method comprising the steps of:

generating, at the first node, a next replacement key pair comprising a next replacement private key and a next replacement public key;

encrypting , at the first node, the next replacement public key to form an encrypted next replacement public key;

sending the next replacement public key from the first node to the second node;

decrypting , at the second node, the encrypted next replacement public key; and

thereafter using the replacement key pair as the active key pair, for use in securing messages between the first and second nodes, and thereafter using the next replacement key pair in place of the replacement key pair, which is stored for use in the subsequent key pair retiring step.

11. The method of claim 10, wherein the step of sending the next replacement public key from the first node to the second node is performed over a network presumed to be secure.

12. A method of secure key replacement in a public key cryptography system, wherein secure messages are transmitted from a first node to a second node over a network presumed to be insecure, the method comprising the steps of:

generating, at the first node, an active key pair comprising an active private key and an active public key, wherein the active key pair is used to secure messages between the first and second nodes according to a public key scheme;

generating, at the first node, a replacement key pair comprising a replacement private key and a replacement public key;

sending the active public key and the replacement public key from the first node to the second node over a secure channel;

when the active key pair is to be retired, performing the steps of:

generating, at the first node, a next replacement key pair comprising a next replacement private key and a next replacement public key; and

sending the next replacement public key from the first node to the second node over the network; and

thereafter using the replacement key pair as the active key pair, for use in securing messages between the first and second nodes, and thereafter using the next replacement key pair in place of the replacement key pair, which is stored for use in a subsequent key pair retiring step.

13. A public key cryptography apparatus for secure communications over an untrusted network between a key server node and a user node, comprising:

user data storage, coupled to the user node of the untrusted network, for storing an active public key and a replacement public key;

key server data storage, coupled to the key server node, for storing an active private key and a replacement private key, wherein the active private key and the active public key are a key pair and the replacement private key and the replacement public key are a key pair; and

means for transmitting a key replacement message from the key server node to the user node, the key replacement message comprising

a next replacement public key and a digital signature proving knowledge by the key server node of both of the active private key and the replacement private key.

FIG. 1

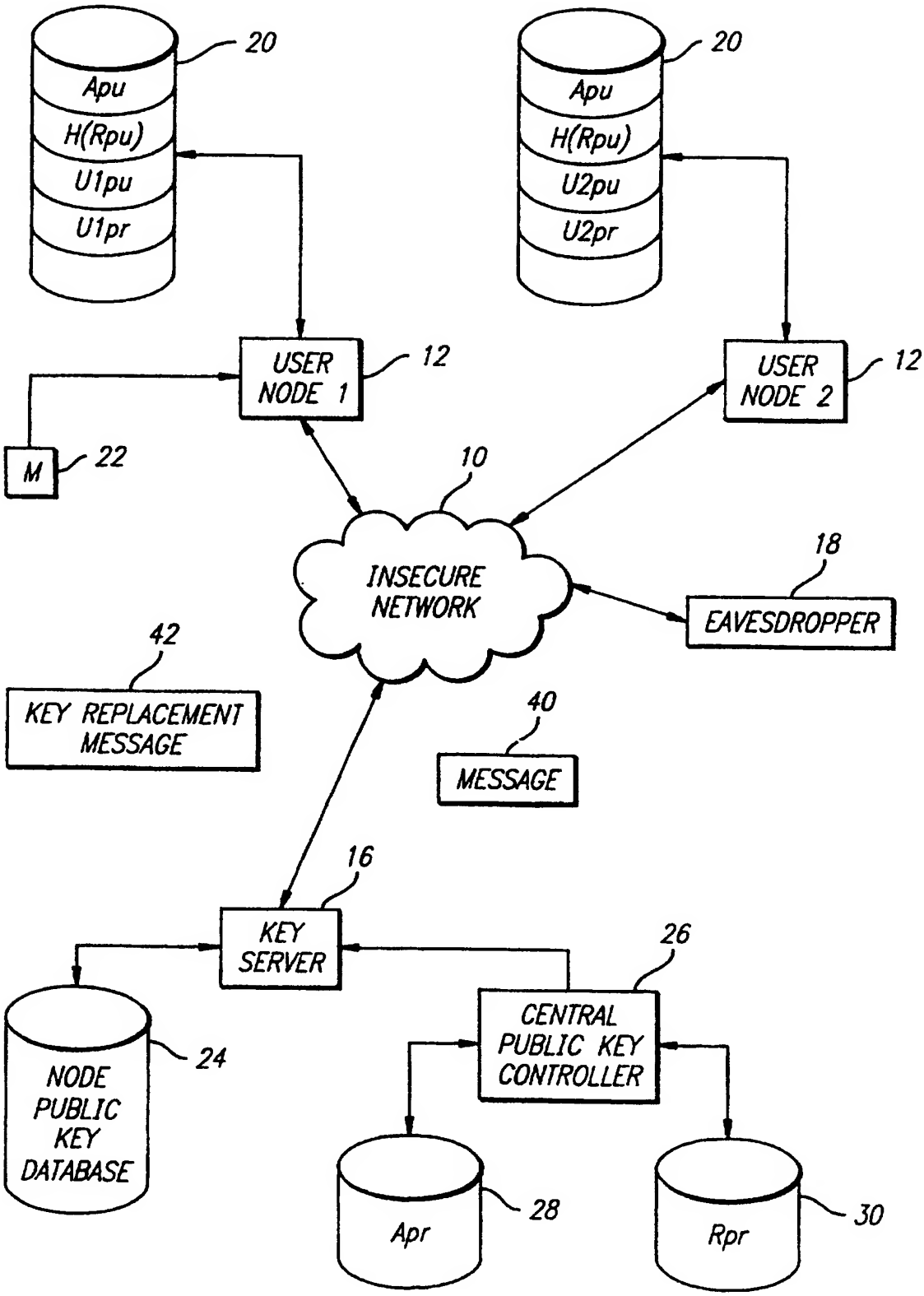


FIG. 2

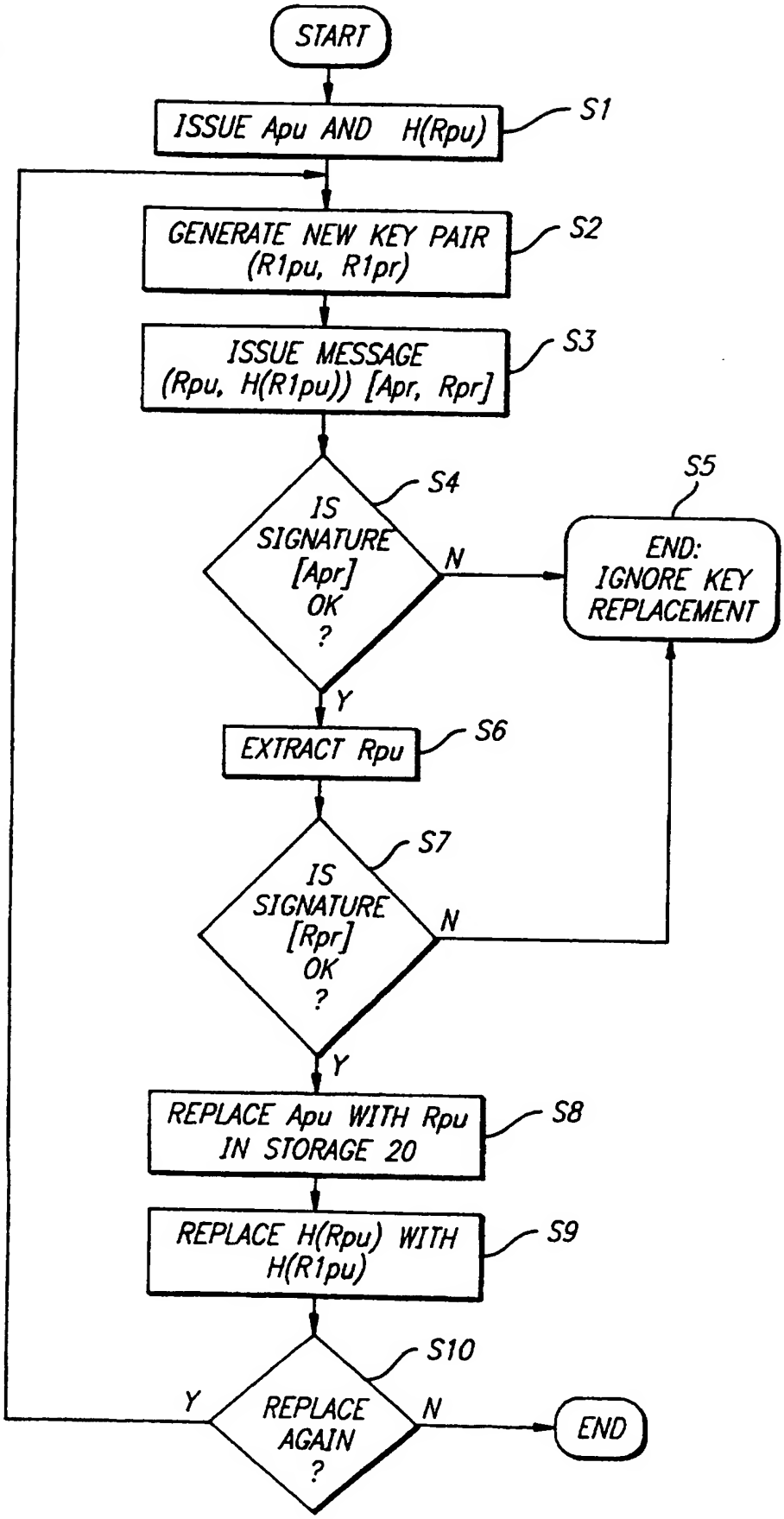


FIG. 3

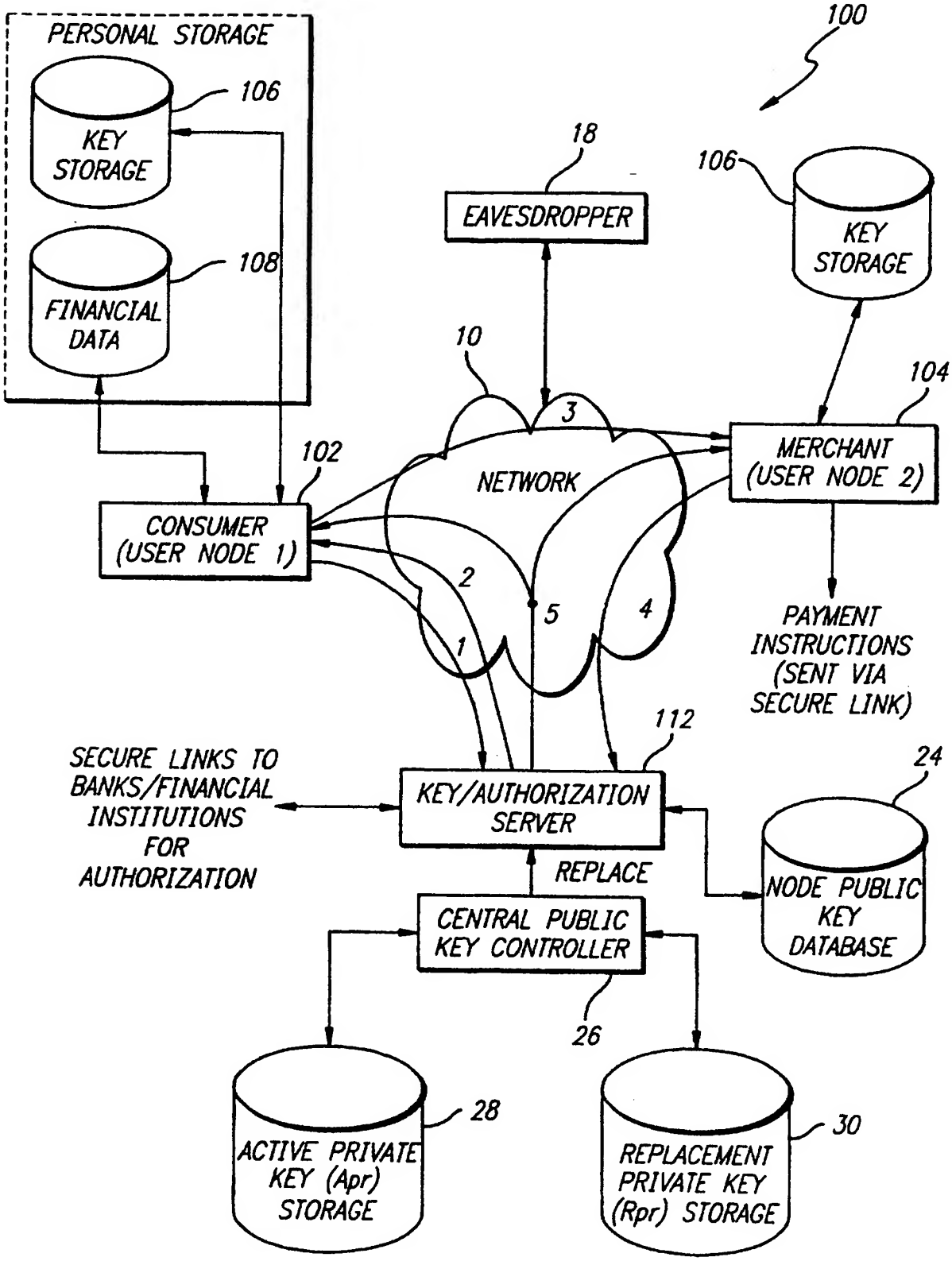


FIG. 4

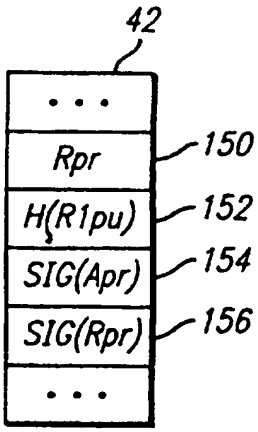


FIG. 6

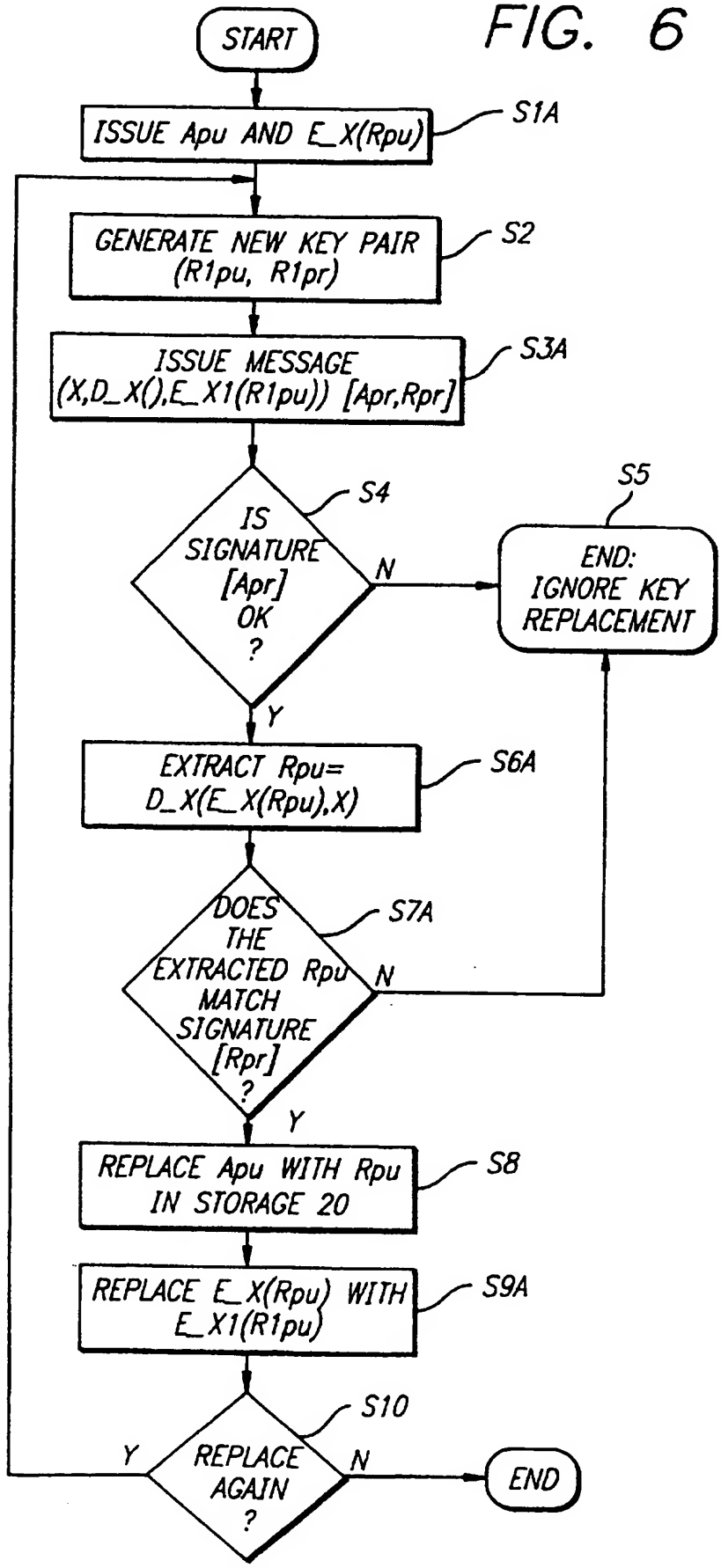


FIG. 7

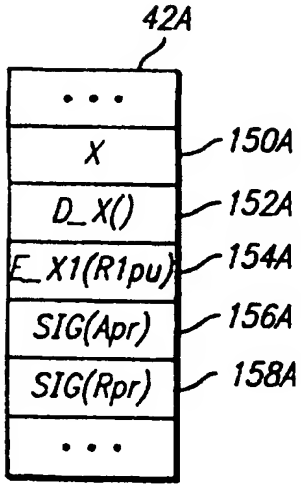
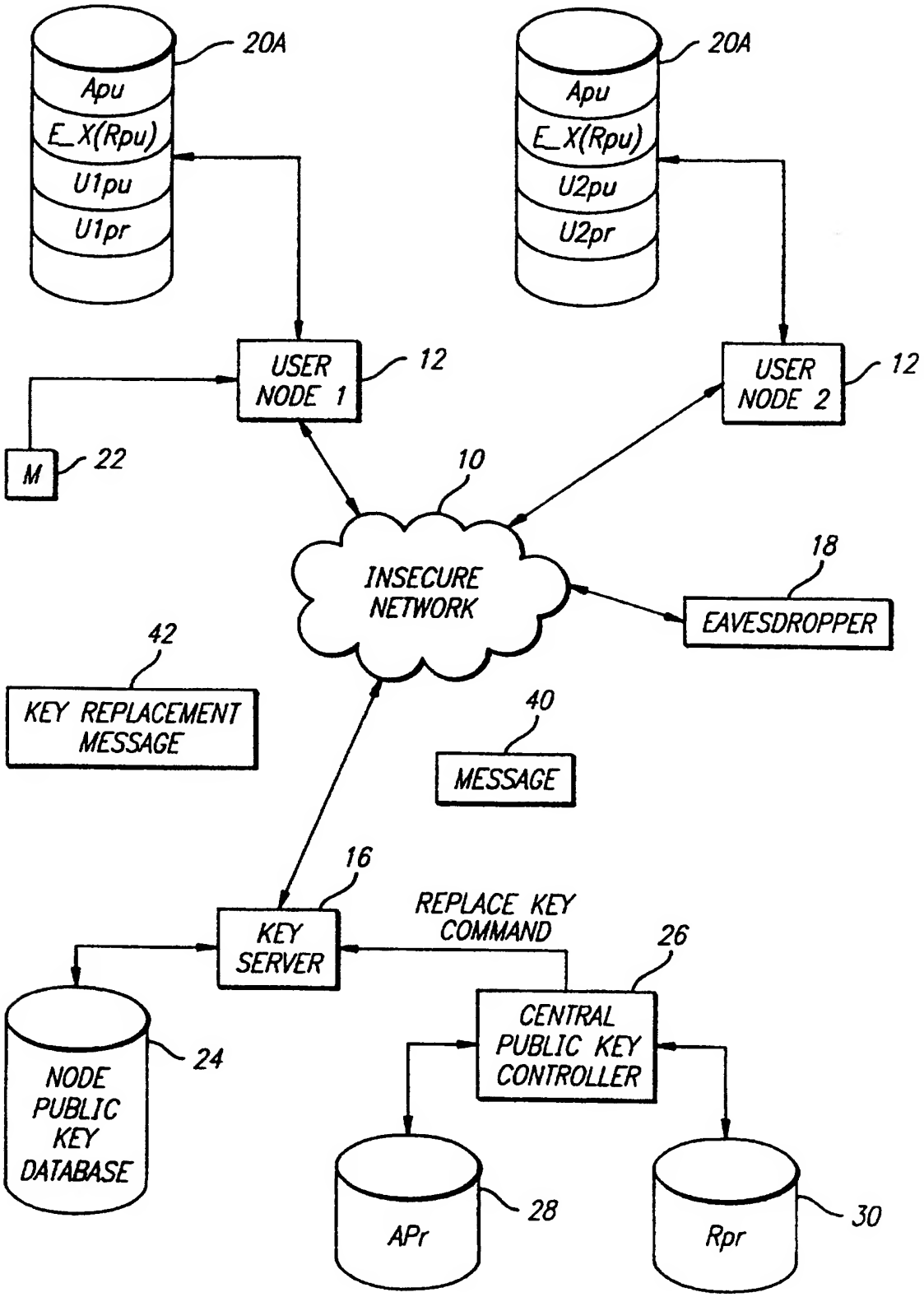


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/02984

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04L 9/08
US CL :380/21
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 380/21, 23, 25, 30, 48, 49

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS
Search terms: key replacement, key update

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 5,469,507 A (CANETTI ET AL.) 21 November 1995; see especially columns 5-7, and 14	13 ---- 1-12
Y	US 4,972,472 A (BROWN ET AL.) 20 November 1990; entire document	1-12
A	US 4,688,250 A (CORRINGTON ET AL.) 18 August 1987; entire document	1-13
A	US 4,993,067 A (LEOPOLD) 12 February 1991; entire document	1-13
A,P	US 5,499,294 A (FRIEDMAN) 12 March 1996; entire document	3,4

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

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Date of the actual completion of the international search
02 APRIL 1997

Date of mailing of the international search report
08 JUL 1997

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/02984

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,799,258 A (DAVIES) 17 January 1989; entire document - see especially Abstract, column 1 lines 52-62, column 2 lines 44-52, and the top of column 6	1-12

Form PCT/ISA/210 (continuation of second sheet)(July 1992)*